

I
EIS

3/7/90

Sea Otter Foraging Behavior and
Hydrocarbon Levels in Prey Following the Exxon Valdez
Oil Spill in Prince William Sound, Alaska

Marine Mammal Study 6

Final Report

December 1993

Angela M. Doroff^a

and

James L. Bodkin^b

U.S. Fish and Wildlife Service
Alaska Fish and Wildlife Research Center
1011 East Tudor Road
Anchorage, AK 99503

DRAFT

^a Present address: U.S. Fish and Wildlife Service; Marine Mammals Management; 4230 University Drive, Suite 310; Anchorage, AK 99508

^b Present address: U.S. National Biological Survey; Alaska Fish and Wildlife Research Center, 1011 East Tudor Road, Anchorage, AK 99503

TABLE OF CONTENTS

ABSTRACT	iv
INTRODUCTION	1
METHODS	3
Study Sites	3
Foraging Observations	3
Scat Analysis	4
Collection and Hydrocarbon Analysis of Prey	5
Data Analysis	6
RESULTS	8
Foraging Behavior	8
Prey Composition	9
Prey Hydrocarbon Analysis	10
DISCUSSION	12
CONCLUSIONS	16
ACKNOWLEDGEMENTS	17
REFERENCES	18

LIST OF TABLES

- Table 1.-- Prey type, size class, proportion of successful dives, and mean number of prey retrieved per dive estimated for sea otters (Enhydra lutris) at three sites in western Prince William Sound, Alaska, during April-July 1991 22
- Table 2.-- Median proportion of dives resulting in the capture of clams, crabs, and mussels for adult and juvenile sea otters (Enhydra lutris) in Prince William Sound, Alaska, 1991 24
- Table 3.-- Composition of sea otter (Enhydra lutris) prey determined by visual observation at three sites in western Prince William Sound, Alaska, during April-July 1991 . 25
- Table 4.-- Estimated percentage of prey type (mussel, clam, crab, and other small invertebrates) found in 253 scat samples examined during 20 April to 2 May 1991 in western Prince William Sound, Alaska 27
- Table 5.-- Hydrocarbon and size class means for bivalves collected subtidally near Squirrel (oiled), Green (oiled), and Montague (non-oiled) islands in western Prince William Sound, Alaska, summer 1991 28

LIST OF FIGURES

Figure 1. Sea otter forage study site locations in western Prince William Sound, 1991 30

ABSTRACT

In summer 1991, sea otter (*Enhydra lutris*) foraging success and prey composition were determined by visual observation at 2 sites affected by shoreline oiling during the Exxon Valdez oil spill (Squirrel and Green islands) and at a non-oiled site (Montague Island) in western Prince William Sound, Alaska. Prey species were also determined by scat analysis at Green Island. Bivalve prey were collected subtidally at each study site to determine petroleum hydrocarbon levels in sea otter prey.

The proportion of successful dives did not differ among sites for adults or between adults (90%) and juveniles (92%). The mean number of prey captured per dive was 1.2 and did not differ among study sites. Size class of sea otter prey was similar among study sites: >96% of the prey items were estimated to be <9 cm.

Adults differed in the proportion of dives retrieving clams ($P = 0.01$), crabs ($P = 0.03$), and mussels ($P = 0.03$) among study sites. Clams were retrieved on 34%, 61% and 44% of successful foraging dives observed at Squirrel ($n = 833$), Green ($n = 759$), and Montague ($n = 752$) islands, respectively. *Saxidomus giganteus* was the most frequently identified clam species. Mussels (*Mytilus edulis*) and crabs (*Telmessus* spp.) contributed $\leq 20\%$ of the total prey items recovered by otters at each study site. Juvenile sea otters in the Green Island site had a significantly higher proportion of dives resulting in the capture of mussels than did adults ($P = 0.02$); no differences were detected in the proportion of dives resulting in clam or crab. Other species contributed $\leq 5\%$ at each study site. Sea otter scat collected at Green Island contained primarily mussels (60%) and clams (46%, $n = 253$).

Tissue samples of subtidal sea otter prey from oiled sites did not differ from the non-oiled site in mean concentrations of alkanes, aromatics, or unresolved complex mixture. Mussel tissue sampled during 1989-1992 in Prince William Sound exhibited, at site-specific areas, hydrocarbon concentrations similar to crude oil (Babcock et al. 1993) and may be of concern for juvenile sea otters and for adults specializing in intertidal prey species.

INTRODUCTION

Following the Exxon Valdez oil spill in March 1989, Prudhoe Bay heavy crude oil spread on the sea surface and on coastal shores from western Prince William Sound to the Alaska Peninsula. In Prince William Sound alone, acute mortality of sea otters at the time of the spill was estimated to be greater than 2,000 otters (Doroff et al. 1993; Garrott et al. 1993). Potential long-term chronic effects of oiled intertidal and subtidal prey on the sea otter population are of concern. Marine bivalves are susceptible to the accumulation of petroleum hydrocarbons from both chronic and acute sources (Blumer et al. 1970; Ehrhardt 1972; Boehm and Quinn 1977).

Shoreline oiling was observed on approximately 24% of 1,182 miles of coastline surveyed within Prince William Sound (Exxon Valdez Oil Spill Damage Assessment Geoprocessing Group 1991). The effect of oil on the abundance of nearshore marine invertebrate populations is unclear. The concentration and persistence of hydrocarbons present in tissues of most of these invertebrate species remains unknown.

Sea otters prey on a wide variety of benthic marine invertebrates (Riedman and Estes 1990) and forage in shallow coastal waters (Wild and Ames 1974), which vary widely in exposure to the open ocean, substrate type, and community composition. Sea otters have high metabolic demands relative to other marine mammals and can consume 20-25% of their body weight per day in invertebrate prey (Kenyon 1969; Costa and Kooyman 1984).

Sea otters have occupied southwestern Prince William Sound since at least the early 1950's (Lensink 1962; Garshelis et al. 1986). The sea otter population in the Prince William Sound spill region was likely near equilibrium density and limited by prey availability before the oil spill occurred (Estes et al. 1981; Garshelis et al. 1986; Johnson 1987). Sea otters in this region spent 59% of daylight hours foraging, while otters in recently reoccupied habitats of eastern Prince William Sound spent only 27% (Garshelis et al. 1986). Therefore, small differences in abundance of prey or net caloric availability due to heavy oiling in portions of the southwestern Sound may lead to reduced carrying capacity and delayed recovery of the sea otter population in this region.

Recovery of sea otter populations may be influenced by several factors. Decreased food availability caused by oil-related prey mortality or consumption of contaminated prey may be detrimental. Prey availability in western Prince William Sound may have declined due to increased mortality of invertebrates at the time of shoreline oiling, or by oil removal activities. In addition, relative prey availability may have been decreased by sea otters avoiding invertebrate prey contaminated with petroleum hydrocarbons. However, we lack the baseline data on abundance and distribution of nearshore invertebrates necessary to estimate a reduction in prey availability. In addition, the effects of ingesting prey contaminated with petroleum hydrocarbons on sea otters are unknown.

Our objectives were to determine if sea otter foraging success and prey composition differed between oiled and non-oiled areas, and to assess hydrocarbon levels in sea otter prey between oiled and non-oiled areas.

METHODS

Study Sites

The study area included sea otter foraging sites at Squirrel, Green, and Montague islands, in western Prince William Sound, Alaska (Figure 1). Sites were selected on the basis of two criteria: 1) degree of shoreline oiling (based on Alaska Department of Environmental Conservation shoreline oiling maps) with Squirrel, Green, and Montague islands representing heavy (>50% of the beach area covered or penetrated with oil), moderate (10-50% of the beach area covered or penetrated with oil) and no shoreline oiling, respectively; and 2) sufficient sea otter densities to obtain foraging data, determined by sea otter survey and capture data from other spill-related studies. In general, the study area was a female area where breeding and pup-rearing occurred (Estes et al. 1981; Garshelis 1983; Riedman and Estes 1990) and foraging data were collected on adults and juveniles of both sexes. Sea otter foraging data were collected in the study area between mid-April and July and subtidal sea otter prey were collected during August 1991.

Foraging Observations

Visual observations of foraging sea otters were made by trained individuals with the aid of high-resolution telescopes (Questar Corporation, New Hope, PA) and 10 X 40 binoculars. Foraging behavior was documented using focal animal sampling (Altmann 1974). A foraging otter was located and observed until a maximum of 50 identifiable prey items

were observed or until visual contact with the animal was lost or foraging ceased. When possible, data recorded for each dive included age (adult, juvenile or unknown) and sex of focal animal, number of prey and relative prey size, dive interval (seconds), surface interval between foraging dives (seconds), and prey item to lowest identifiable taxon. Prey were classified into one of 5 size classes (<5 cm, ≥ 5 to <7 cm, ≥ 7 cm to <9 cm, ≥ 9 to <12 cm and ≥ 12 cm). Size class of prey was estimated by observers based on the mean forepaw width (4.5 cm) and mean skull width (10 cm) for adult sea otters in this region (Johnson 1987, U.S. Fish and Wildlife Service, unpublished data). Adult animals were categorized as male, independent female or female with a pup. Small (estimated at ≤ 18 kg), dark-headed otters were identified as juveniles. Foraging dives were classified as successful (prey item captured), unsuccessful (no prey item captured) or as producing an unknown result (observer could not determine if the dive was successful or unsuccessful). The locations of foraging sea otters were recorded on a Geographic Information System coverage map gridded with a Universal Transverse Mercator projection. Data were collected only during daylight hours and during all tidal cycles.

Scat Analysis

During 20 April to 2 May 1991, 253 sea otter scat samples were examined in the field along 8.5 km of beach within the Green Island study site (Figure 1). For each scat sample encountered, the species of prey (when possible) were recorded within each scat. The estimated percentage that each prey type (mussel, clam, crab, or other) contributed to the entire scat was categorized as follows: 100, 90, 75, 50, 25, 10, and 5%.

Collection and Hydrocarbon Analysis of Prey

At each study site, clam species identified as sea otter prey were collected and tissues were analyzed for hydrocarbon content. Coordinates of foraging observations were plotted for each study site. The outermost coordinate locations delineated a polygon over which a grid of 100-m² plots was laid. Ten 100-m² plots were chosen randomly within each study site, and SCUBA divers searched for prey within each plot, beginning at the boat anchor. The boat anchor location was haphazard within each of the plot boundaries. Clams were recovered using a venturi dredge (Keene Engineering, Northridge, CA). Water depth averaged 8 m (range, 5-12 m). Clams were brought to the surface in nylon mesh dive bags, wrapped in chemically cleaned aluminum foil (acetone-and hexane-washed) and frozen whole. During prey collection, divers attempted to obtain 3 Saxidomus giganteus within each plot. However, this could not be accomplished in all plots and, where possible, 3 of each clam species encountered were submitted for analysis. When more than 3 clams of the same species were retrieved from a single plot, 3 were randomly selected for hydrocarbon analyses. Clams were thawed in the laboratory and soft tissue was removed (using instruments cleaned with acetone and hexane) from the shell and placed in chemically clean jars, weighed and refrozen. Samples were shipped to the Geochemical and Environmental Research Group (GERG) at College Station, Texas, for analysis of the hydrocarbon content. The tissue extraction method used in the analysis was developed by MacLeod et al. (1985) and modified by Wade et al. (1988, 1993) and Jackson et al. (1993). Laboratory methodology for the hydrocarbon analysis for this study was standardized with all Natural Resource Damage Assessment Studies by GERG (GERG standard operating procedures 8901-

8905).

Data Analysis

The foraging record is defined in this paper as the foraging data specific to a focal animal and was used as the sample unit in the analyses of foraging behavior. The sample unit in the analysis of dive and surface intervals was individual dives.

The percentage of successful dives was determined for all foraging records of adult and juvenile sea otters having ≥ 10 dives. Dives of unknown result were not included in this analysis. An arcsine transformation of the square-root of the proportion of successful dives was used to normalize distributions and an analysis of variance (ANOVA) was used to test for differences in foraging success among sites and between adults and juveniles.

Number of prey items captured per dive was averaged for each foraging record by site. Dives resulting in the capture of mussels were excluded from this analysis due to the difficulty in obtaining accurate counts on a per dive basis. Dives of unknown result were not used in this analysis. ANOVA was used to test for differences in the number of prey retrieved per dive among sites.

Mean dive and surface intervals were tested among study sites and prey types (clams, crabs, and mussels) by a two-way ANOVA for an unbalanced sample.

Foraging records for each focal animal having ≥ 10 foraging dives were summarized into the proportion of dives resulting in the capture of clams, crabs, or mussels within each study site. Kruskal-Wallis nonparametric tests were used to determine differences in the proportion of clams, crabs, and mussels captured among sites for adult sea otters and between adults and juveniles (sample sizes were sufficient to test age differences only for the Green Island study site).

Hydrocarbon concentrations were reported from the lab in ng/g wet weight for alkanes and aromatics, and in $\mu\text{g/g}$ wet weight for UCM (unresolved complex mixture). Mean concentrations of total alkanes, total aromatics and UCM were tested among study sites by ANOVA procedures. Prior to analysis, data were transformed by a $\log_{10}(x_i + 1)$ to normalize the distribution.

RESULTS

Foraging Behavior

At Squirrel Island, 69 foraging records were observed (68 adults and 1 juvenile). Thirty-eight foraging records (29 adults and 9 juveniles) were observed at Green Island and 72 foraging records (69 adults and 3 juveniles) were observed at Montague Island.

Sea otters at all sites recovered prey items on 87-92% of their foraging dives and foraging success did not differ among sites ($F = 1.23$, $P = 0.29$) (Table 1). Mean foraging success rates were 90% ($n = 82$) for adult and 92% ($n = 10$) for juvenile sea otters in all study sites combined and did not differ significantly ($F = 0.50$, $P = 0.48$).

Mean number of prey retrieved per dive were 1.2, 1.0, and 1.3 for Squirrel, Green, and Montague Islands, respectively; differences were not detected among sites ($F = 2.19$, $P = 0.11$). Size class was estimated for 1,867 prey items; the majority of prey items, 96% or greater, were <9 cm in all sites (Table 1).

Mean dive intervals varied from 43 to 88 seconds, and surface intervals varied from 37 to 48 seconds for all prey types within the study sites. Dive intervals differed significantly for dives retrieving clams (80-119 seconds), mussels (20-35 seconds), and crabs (63-82 seconds) among study sites ($F = 19.83$, $P < 0.001$), and among prey types ($F = 135.92$, $P < 0.001$), and the interaction between site and prey type also differed

($F = 24.16, P < 0.001$).

Prey Composition

Adults differed in the proportion of dives resulting in the capture of clams ($\chi^2 = 9.73, P = 0.01$), crabs ($\chi^2 = 7.03, P = 0.03$), and mussels ($\chi^2 = 7.21, P = 0.03$) among sites (Table 2). The median proportion of dives resulting in the capture of clams was higher than that for mussels or crabs in all study sites for adults and was less (0.29) for the Squirrel Island than for Green (0.75) or Montague (0.62) islands. Sample sizes were insufficient to test for differences in prey composition related to sex or reproductive status. Juvenile sea otters in the Green Island site captured mussels on a significantly higher proportion of dives than did adults ($\chi^2 = 5.73, P = 0.02$) (Table 2). Differences between adult and juvenile sea otters were not detected for the proportion of dives in which clam or crab were captured (in the Green Island area). Sample sizes were insufficient to test for age class differences of the proportion of dives resulting in the capture of clams, crabs, and mussels in the Squirrel and Montague island study sites.

Clams were retrieved on 34, 61, and 44% of successful sea otter foraging dives at Squirrel ($n = 833$), Green ($n = 759$), and Montague ($n = 752$) islands, respectively (Table 3). Saxidomus giganteus was the most commonly identified clam in the sea otter diet for all study sites. Other clam species identified in all study sites were Mya spp. and Protothaca staminea. Mussels (Mytilis edulis), and crabs (primarily Telmessus spp.) each contributed 20% or less of the identified species for each study site. Other prey types observed

included: limpets (Notoacmea spp.), barnacles (Balanus spp.), cockles (Clinocardium spp.), scallops (Chlamys spp.), sea cucumbers (Cucumaria spp.), fat innkeepers (Echiurus echiurus alaskensis), octopus (Octopus spp.), sea stars (Pisaster spp.), jingles (Pododesmus spp.), sunflower sea stars (Pycnopodia helianthoides), sea urchins (Strongylocentrotus spp.), chitons (class Polyplacophora) and tunicates (class Ascidiacea). These species contributed 5% or less to otter diets at each study site (Table 3).

Fifty-six percent of the 253 scat samples examined in the Green Island study site contained more than one prey species (Table 4). Mussels were observed in 153 of 253 (60%) sea otter scat and clams were observed in 116 of 253 (46%) scat examined. Clam species were primarily P. staminea and S. giganteus with trace amounts of Humilaria kennerleyi and Gari californica. Crab and other small invertebrates were found in 19 and 20%, respectively of scat sampled. Of scats containing a single prey type, 76 contained only mussels, 23 contained only clams and 13 contained either scallops (Chlamys sp.), snails (Natica sp.), cockles (Clinocardium sp.), or limpets (Notoacmea scutum).

Prey Hydrocarbon Analysis

A total of 79 prey samples were collected for hydrocarbon analyses. Twenty-five prey were collected in 7 plots at Squirrel Island; 33 prey in 7 plots at Green Island, and 21 prey in 6 plots at Montague Island. P. staminea (n = 24), Mya spp. (n = 23), and S. giganteus (n = 20) were most frequently collected. Species composition and size class samples within sites are presented in Table 5.

Tissue samples of subtidal bivalves obtained from sites which had received heavy to moderate shoreline oiling in 1989 had no detectable differences in mean total alkane ($F = 2.35$, $P = 0.10$), aromatic ($F = 0.16$, $P = 0.85$) and UCM ($F = 0.56$, $P = 0.57$) concentrations from the site where no shoreline oiling occurred (Table 5). Mean concentrations of total alkanes and aromatics were slightly higher, however, for tissue samples collected at Green Island than those from Squirrel and Montague islands. At all sites, Mya arenaria contained the highest concentration of total alkanes of all species sampled.

DISCUSSION

Although foraging success was high (90% for all observations), the majority of clams (95% of 1,126) observed were small (estimated to be <7 cm). Garshelis et al. (1986) reported clams captured by sea otters rarely exceeded 6 cm in the Green Island site during 1980-1981. During 1991, 79% (n = 479) of the clams captured at Green Island were estimated to be <5 cm, 20% ranged from ≥ 5 -<7 cm, and none were estimated to be greater than 9 cm. Mean shell length for clams recovered in the dredge samples in the Green Island area ranged from 3.3 to 4.7 cm.

Dive duration and surface intervals between dives were variable for individuals but significantly different depending on the type of prey captured. Individual animals, water depth, geographic location and food item all contribute to variation in duration of foraging dives (Estes et al. 1981; Garshelis 1983). Sea otters at Squirrel, Green, and Montague islands foraged on the same principal species in 1991 as were observed in previous years (Calkins 1978; Garshelis et al. 1986; Johnson 1987) suggesting there has been no detectable shift in prey composition over time or as a result of shoreline oiling at these study sites. Clams, mussels and crabs were the primary prey of sea otters at all sites, however, there were differences in the proportion with which these prey were captured among sites. Differences in the proportions of prey type captured by sea otters among sites may have been influenced by the proportion of unidentified prey within each site (Table 3) or by variation in prey availability within each site. There was no replication of treatment types (heavy oil, moderate oil, and no oil), therefore we have no measure of natural variation within each

treatment.

Prey composition determined from scat contents also indicated mussels, clams, and crabs to be important prey of sea otters. Sea otters haul out most frequently during the winter in Prince William Sound; therefore, these data primarily represent the overwinter diet near Green Island (Johnson 1987; VanBlaricom 1988). Johnson (1987) examined 3,275 scat in the Green Island site during 1974-1984 and found 58, 34, 36, and 16% of the scat contained clams, mussels, crabs, and other species, respectively. In our sample from the same region, we observed mussels most frequently (60%). Whether the observed differences reflect changes in prey use over time, changes in the ratio of adults and juveniles using the haul-out through time, or variation in scat content between observation periods is unknown.

Determination of sea otter prey composition through visual observation or scat analysis can yield different results; both methods have inherent biases. Prey composition based on visual observations is biased toward: 1) prey captured from near-shore areas, 2) larger prey items (greater than the paw size of the animal), and 3) prey captured during daylight hours. Prey composition based on scat analysis is biased against larger prey where no hard parts are ingested. Scat analysis also cannot reveal potential variation in diet between adult and juvenile or male and female otters.

Adult sea otters foraged primarily on species found in the subtidal, whereas juveniles had a higher proportion of an intertidal species, the mussel, in their diet based on visual observation. Johnson (1987) also reported dietary differences between adult (19% mussel

and 59% clam) and juvenile (63% mussel and 16% clam) sea otters at Green Island during 1974-1984. In California, Estes et al. (1981) found that juveniles commonly foraged in water ranging from 1 to 2 fathoms while adults nearly always foraged in deeper water. Mussels can easily be obtained by foraging sea otters because they occur intertidal and require little effort to capture (Estes et al. 1981; VanBlaricom 1988). Mean dive intervals for mussels were shorter than those recorded for other prey. However, mussels are less valuable calorically than other sea otter prey (Garshelis 1983).

Mean total aromatic and UCM concentrations in intertidal mussel tissue collected at our study site on Green Island during 1989 were 2,566 ng/g (\pm 853) and 171.4 μ g/g (\pm 58.6), respectively (Andres and Cody (MS)). These values are as much as 40 times greater than the mean levels we observed in the subtidal clam tissue at Green Island sampled in 1991. Unfortunately, no intertidal mussels were collected in 1991 to assess the persistence of hydrocarbons in the mussel tissues at the Green Island site. Andres and Cody (MS) also reported hydrocarbon levels in mussel tissue of 82 ng/g (\pm 21) and 7.4 μ g/g (\pm 1.7) for total aromatic and UCM, respectively, from our Montague Island study site; aromatic and UCM levels were slightly lower in the subtidal bivalve tissue collected 1991. Other sites in Prince William Sound were sampled annually (1989-1992) and, at some sites, mussel tissue and the underlying sediments consistently contained high concentrations (up to 50 parts per million) of total aromatic hydrocarbons (Babcock et al. 1993; Rounds et al. 1993).

Juvenile sea otters foraged on mussels to a greater extent than adults. However, individual adults and juveniles may specialize on only a few species, some of which occur in

the intertidal (Ralls et al. 1988; Riedman and Estes 1990). Therefore, juveniles and individual adults specializing in intertidal species could have a higher probability of encountering hydrocarbon contamination in their prey than individuals foraging in the subtidal regions.

CONCLUSIONS

Sea otter foraging success, in terms of the percentage of successful dives or mean number of prey items captured per dive, was not affected in the oiled area two years post-spill. Prey composition (primarily clam, mussel, and crab) was similar among oiled and non-oiled study sites and to pre-spill data from the western Prince William Sound region. Adult sea otters foraged primarily in the subtidal region, while juveniles foraged more frequently intertidally. Tissues of subtidal bivalve prey tested for hydrocarbon content did not differ regardless of the degree of shoreline oiling. Mussel tissue sampled 1989-1992 in the intertidal regions exhibited, in site specific areas, hydrocarbon concentrations similar to crude oil (Babcock et al. 1993). Contamination of mussels and other intertidal prey species may be of concern for juvenile sea otters and for adults specializing in the use of intertidal prey.

ACKNOWLEDGEMENTS

This work was conducted as part of Exxon Valdez Oil Spill Natural Resources Damage Assessment process. We thank K. Modla who was a primary observer during data collection and assisted with data entry. D. Bruden, C. Doroff and M. Fedorko also assisted with data collection. B. Ballachey, L. Holland-Bartels, A. R. DeGange, D. Mulcahy, K. Oakley, M. Riedman and two anonymous reviewers provided draft reviews of the manuscript and made many valuable suggestions. We thank M. Ronaldson for her help in preparing the manuscript.

REFERENCES

- Altmann, J. (1974.) Observational study of behavior: sampling methods. *Behavior* 49:227-267.
- Andres, B. A., and Cody, M. M. (MS Draft.) The effects of the Exxon Valdez spill on black oystercatchers breeding in Prince William Sound. Bird Study No. 12, Restoration Study No. 17. U.S. Fish and Wildlife Service, Anchorage.
- Babcock, M., Irvine, G., Rice, S., Rounds, P., Cusick, J., and Brodersen, C. C. (1993.) Oiled mussel beds in Prince William Sound two and three years after the Exxon Valdez oil spill. In "Exxon Valdez Oil Spill Symposium Program and Abstracts," pp. 184-185. The Oil Spill Public Information Center, 645 G Street, Anchorage, AK.
- Blumer, M., Souza, G., and Sass, J. (1970.) Hydrocarbon pollution of edible shellfish by an oil spill. *Marine Biology* 5:195-202.
- Boehm, P. D., and Quinn, J. G. (1977.) The persistence of chronically accumulated hydrocarbons in the hard shell clam Mercenaria mercenaria. *Marine Biology* 44:227-233.
- Calkins, D. G. (1978.) Feeding behavior and major prey species of the sea otter, Enhydra lutris, in Montague strait, Prince William Sound, Alaska. *Fisheries Bulletin* 76(1):125-131.
- Costa, D. P., and Kooyman, G. L. (1984.) Contribution of specific dynamic action to heat balance and thermoregulation in the sea otter Enhydra lutris. *Physiological Zoology* 57(2):199-203.
- Doroff, A., DeGange, A. R., Lensink, C., Ballachey, B. E., Bodkin, J. L., and Bruden, D.

- (1993.) Recovery of sea otter carcasses following the Exxon Valdez oil spill. In "Exxon Valdez Oil Spill Symposium, Program and Abstracts," pp. 285-288. The Oil Spill Public Information Center, 645 G Street, Anchorage, AK.
- Ehrhardt, M. (1972.) Petroleum hydrocarbons in oysters from Galveston Bay. *Environmental Pollution* 3:257-271.
- Estes, J. A., Jameson, R. J., and Johnson, A. M. (1981.) Food selection and some foraging tactics of sea otters. In "Worldwide furbearer conference proceedings, 3-11 August 1980" (J. A. Chapman and D. Pursley, eds.), pp. 606-641. Frostburg, MD.
- Exxon Valdez Oil Spill Damage Assessment Geoprocessing Group. (1991.) The Exxon Valdez oil spill natural resource damage assessment and restoration: A report on oiling to environmentally sensitive shoreline. Draft. In "Exxon Valdez Oil Spill Damage Assessment Geoprocessing Group", pp. 1-31. Exxon Valdez Oil Spill Technical Services #3, GIS Mapping and Statistical Analysis. Alaska Department of Natural Resources, and U.S. Fish and Wildlife Service, Anchorage, AK.
- Garrott, R. A., Eberhardt, L. L., and Burn, D. M. (1993.) Impact of the Exxon Valdez oil spill on sea otter populations. *Marine Mammal Science*. (in press).
- Garshelis, D. L. (1983.) Ecology of sea otters in Prince William Sound, Alaska. Ph.D. thesis, University of Minnesota, MN, 321 pp.
- Garshelis, D. L., Garshelis, J. A., and Kimker, A. T. (1986.) Sea otter time budgets and prey relationships in Alaska. *Journal of Wildlife Management* 50(4):637-647.
- Jackson, T. J., Wade, T. L., McDonald, T. J., Wilkinson, D. L., and Brooks, J. M. (1993.) Polynuclear aromatic hydrocarbon contaminants in oysters from the Gulf of

- Mexico (1986-1990). Environmental Pollution (in press).
- Johnson, A. M. (1987.) Sea otters of Prince William Sound, Alaska. Unpublished Report, U.S. Fish and Wildlife Service, Alaska Fish and Wildlife Research Center, Anchorage, AK.
- Kenyon, K. W. (1969.) The sea otter in the eastern Pacific Ocean. North American Fauna 68. 352 pp.
- Lensink, C. J. (1962.) The history and status of sea otters in Alaska. Ph.D. thesis, Purdue University, West Lafayette, IN. 188 pp.
- McLeod, W. D., Brown, D. W., Friedman, A. J., Burrow, D. G., Mayes, O., Pearce, R. W., Wigren, C. A., and Bogar, R. G. (1985.) Standard analytical procedures of the NOAA National Analytical Facility 1985-1986. Extractable Toxic Compounds. 2nd Edition. U.S. Department of Commerce, NOAA/NMFS. NOAA Tech. Memo. NMFS f/NWC-92.
- Ralls, K., Hatfield, B., and Siniff, D. B. (1988.) Feeding patterns of California sea otter. In "Population Status of California Sea Otters" (D. B. Siniff and K. Ralls, eds.), pp. 84-105. Final report to the Minerals Management Service, U.S. Dept. Int. 14-12-001-3003.
- Riedman, M. L., and Estes, J. A. (1990.) The Sea Otter (Enhydra lutris): Behavior, Ecology, and Natural History. U.S. Fish and Wildlife Service Biological Report 90(14). 126 pp.
- Rounds, P., S. Rice, Babcock, M. M., and Brodersen, C. C. (1993.) Variability of Exxon Valdez hydrocarbon concentrations in mussel bed sediments. In "Exxon Valdez Oil Spill Symposium Program and Abstracts", pp. 182-183. The Oil Spill Public

Information Center, 645 G Street, Anchorage, AK.

- VanBlaricom, G. R. (1988.) Effects of foraging by sea otters on mussel-dominated intertidal communities. In "The community ecology of sea otters" (G. R. VanBlaricom and J. A. Estes, eds.), pp. 48-91. Springer-Verlag, Berlin, West Germany.
- Wade, T. L., Atlas, E. L., Brooks, J. M., Kennicutt II, M. C., Fox, R. G., Sericano, J., Garcia, B., and DeFreitas, D. (1988.) NOAA Gulf of Mexico Status and Trends Program: Trace Organic Contaminant Distribution in Sediments and Oysters. *Estuaries* 11:171-179.
- Wade, T. L., Jackson, T. J., McDonald, T. J., Wilkinson, D. L., and Brooks, J. M. (1993.) Oysters as biomonitors of the APEX Barge oil spill, Galveston Bay, Texas. In "Proceedings, 1993 International Oil Spill Conference, March 29-April 1, 1993." Tampa, FL.
- Wild, P. W., and Ames, J. A. (1974.) A report on the sea otter, (Enhydra lutris) L., in California. California Department of Fish Game. Marine Resources Technical Report 20. 93 pp.

Table 1.-- Prey type, size class, proportion of successful dives, and mean number of prey retrieved per dive estimated for sea otters (*Enhydra lutris*) at three sites in western Prince William Sound, Alaska, during April-July 1991.

Prey type	Size class (cm)	Squirrel Island	Green Island	Montague Island
Clam	<5	63%	79%	49%
	≥5 <7	28%	20%	46%
	≥7 <9	8%	1%	5%
	≥9 <12	1%	0%	0%
	≥12	<1%	0%	0%
		(n = 296)	(n = 479)	(n = 351)
Mussel	<5	100%	100%	100%
		(n = 142)	(n = 159)	(n = 53)
Crab	<5	18%	21%	43%
	≥5 <7	43%	71%	52%
	≥7 <9	30%	7%	5%
	≥9 <12	7%	0%	0%
	≥12	2%	0%	0%
		(n = 90)	(n = 14)	(n = 112)

Table 1.-- Continued.

Prey type	Size class (cm)	Squirrel Island	Green Island	Montague Island
All Prey ^a	< 5	63%	79%	49%
	≥ 5 < 7	23%	17%	42%
	≥ 7 < 9	10%	4%	8%
	≥ 9 < 12	3%	< 1%	< 1%
	≥ 12	1%	0%	1%
		(n = 598)	(n = 690)	(n = 579)
Mean number of prey per dive ^b		1.2	1.0	1.3
Percentage of successful dives		87%	92%	90%

^a Includes clams, mussels, crab, and all other prey identified as to size class.

^b Dives resulting in capture of mussels were excluded for this analysis due to the difficulty in obtaining accurate counts on a per dive basis.

Table 2.-- Median proportion of dives resulting in the capture of clams, crabs, and mussels for adult and juvenile sea otters (*Enhydra lutris*) in Prince William Sound, Alaska, 1991.

Age class	Green Island				Squirrel Island				Montague Island			
	Clam ^a	Crab ^b	Mussel ^b	N ^c	Clam ^a	Crab ^b	Mussel ^b	N ^c	Clam ^a	Crab ^b	Mussel ^b	N ^c
Adults	0.75	0.0	0.0 ^d	15 (356)	0.29	0.03	0.06	34 (754)	0.62	0.07	0.0	28 (531)
Juveniles	0.16	0.0	0.44 ^d	8 (365)	--	--	--	--	0.17	0.41	0.0	2 (59)

^a Significant differences among areas in the proportion of dives resulting in the capture of clam ($P = 0.01$) by adults determined by a Kruskal-Wallis test.

^b Significant differences among areas in the proportion of dives resulting in the capture of crab ($P = 0.03$) and mussel ($P = 0.03$) by adults determined by Kruskal-Wallis tests.

^c Number of foraging records (total number of foraging dives).

^d Significant differences among age classes in the proportion of dives capturing mussels at Green Island ($P = 0.02$) determined by a Kruskal-Wallis test.

Table 3.-- Composition of sea otter (Enhydra lutris) prey determined by visual observation at three sites in western Prince William Sound, Alaska, during April-July 1991.

	Squirrel	Green	Montague
	Island	Island	Island
	(%)	(%)	(%)
Clam ^a	34	61	44
<u>Mya</u> spp.	2	-	3
<u>Protothaca staminea</u>	3	5	<1
<u>Saxidomus giganteus</u>	21	20	9
<u>Tresus capax</u>	<1	<1	<1
Unknown Clams	73	75	87
Mussel ^a	17	20	7
<u>Mytilus edulis</u>	100	100	100
Crab ^a	11	2	14
<u>Telmessus</u> spp.	46	27	72
Unknown Crabs	54	73	28
Other	5	4	4
<u>Balanus</u> spp.	3	12	-
<u>Chlamys</u> spp.	-	-	6

Table 3.-- Continued.

	Squirrel	Green	Montague
	Island	Island	Island
	(%)	(%)	(%)
<u>Clinocardium</u> spp.	21	3	33
<u>Cucumaria</u> spp.	5	-	-
<u>Echiurus echiurus</u>	3	67	12
<u>Notoacmea</u> spp.	3	-	-
<u>Octopus</u> spp.	3	-	3
<u>Pisaster ochraceus</u>	47	12	39
<u>Pododesmus macrochisma</u>	-	3	-
<u>Pycnopodia helianthoides</u>	3	-	-
<u>Strongylocentrotus</u> spp.	10	-	3
Chiton (class Polyplacophora)	3	-	-
Tunicate (class Ascidiacea)	-	3	3
Unknown prey	33	12	30

^a Adults differed in the proportion of dives retrieving clam ($P = 0.01$), crab ($P = 0.03$), and mussel ($P = 0.03$) among study areas.

Table 4.-- Estimated percentage of prey type (mussel, clam, crab, and other small invertebrates) found in 253 scat samples examined during 20 April to 2 May 1991 in western Prince William Sound, Alaska.

Prey type	Estimated percentage							Occurrence in sample (percentage)
	100%	90%	75%	50%	25%	10%	5%	
Mussel ^a	76	24	10	13	14	6	10	153 (60%)
Clam ^b	23	22	8	15	21	10	17	116 (46%)
Crab ^c	0	2	2	5	21	10	7	47 (19%)
Other ^d	13	4	5	8	4	6	10	50 (20%)

^a Mytilus edulis.

^b Protothaca staminea, Saxidomas giganteus, Humilaria kennerleyi, Gari californica: includes unidentified shell fragments.

^c Species not identified.

^d Other is equivalent to one or more of the following species: scallop (Chlamys spp.), snail (Natica sp.), cockle (Clinocardium spp.), limpet (Notoacmea scutum), and other unidentified snail shell fragments.

Table 5.-- Hydrocarbon and size class means for bivalves collected subtidally near Squirrel (oiled), Green (oiled), and Montague (non-oiled) islands in western Prince William Sound, Alaska, summer 1991.

Sample location and species sampled	Total alkanes (ng/g)	Total aromatics (ng/g)	Unresolved complex mixture ($\mu\text{g/g}$)	Mean shell length (mm)	Mean wet meat mass (g)	N
Squirrel Island						
<u>Humilaria kennerleyi</u>	788.5	48.4	14.8	46	7.8	3
<u>Mya arenaria</u>	1752.6	79.4	0.0	41	4.4	4
<u>Protothaca staminea</u>	629.0	55.6	3.9	44	10.0	6
<u>Saxidomas giganteus</u>	900.3	51.7	6.3	51	14.6	11
<u>Serripes groenlandicus</u>	1225.2	57.0	6.3	56	16.2	1
Site mean \pm SD	971.2 \pm 712.0	56.9 \pm 18.7	5.7 \pm 8.3	47 \pm 17.4	11.2 \pm 6.1	25
Green Island						
<u>Gari californica</u>	1278.2	39.7	3.7	47	0.4	4
<u>Humilaria kennerleyi</u>	1034.2	74.7	56.1	33	2.7	1
<u>Mya arenaria</u>	1494.4	68.8	4.0	40	4.1	15

Table 5.-- Continued.

Sample location and species sampled	Total alkanes (ng/g)	Total aromatics (ng/g)	Unresolved complex mixture ($\mu\text{g/g}$)	Mean shell length (mm)	Mean wet meat mass (g)	N
Green Island (continued)						
<u>Protothaca staminea</u>	790.2	54.8	0.5	41	8.0	9
<u>Saxidomas giganteus</u>	897.8	45.9	0.5	41	8.2	4
Site mean \pm SD	1189.9 \pm 1033.0	58.9 \pm 18.7	4.1 \pm 10.9	41 \pm 6.1	6.3 \pm 3.5	33
Montague Island						
<u>Gari californica</u>	823.3	49.2	3.8	49	5.5	1
<u>Humilaria kennerleyi</u>	569.1	59.7	11.6	52	13.7	2
<u>Mya arenaria</u>	996.4	72.5	1.2	48	7.1	4
<u>Protothaca staminea</u>	806.2	52.2	4.7	41	8.3	9
<u>Saxidomas giganteus</u>	843.0	49.0	0.3	33	4.0	5
Site mean \pm SD	829.4 \pm 163.9	55.9 \pm 12.9	3.6 \pm 6.4	42 \pm 7.9	7.4 \pm 4.0	21

FIGURE LEGENDS

Figure 1. Sea otter forage study site locations in western Prince William Sound, 1991.

Prince William Sound is located in south-central Alaska.

